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THE EARLY HISTORY OF RADIO ASTRONOMY

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The organizers of this Conference have asked me to present a paper on the early history of radio astronomy, using personal experience where possible. Upon further inquiry, I found that this history should end around early 1950, which makes the task of using personal experience rather hard, as I started graduate studies in that year. The literature on the subject contains a wealth of material on the early days, however, and since the science is so young, the historian can still talk to many of the original investigators. Since most of the early history can be found in the introductions to textbooks and popular books, this paper will necessarily contain many items well known to the reader.

Contrary to popular belief, radio astronomy did not start with Jansky's discovery in 1932, but actually very shortly after Hertz produced and measured Maxwell's electromagnetic waves in 1887. And believe it or not, it was Thomas Alva Edison himself who, in 1890, proposed an experiment involving a radio telescope weighing many megatons! Edison reasoned that since disturbances were seen on the sun in visual light, they might also radiate at radio wavelengths. Edison planned to put a loop of telephone wires around a huge field of iron ore in New Jersey! The ore was magnetite, which becomes magnetized by induction. The electromagnetic disturbances from the sun might magnetize the ore; this might cause an induction current in the telephone wires, which could then be listened to. The poles for the telephone wires actually arrived on the site, but there is no record of the actual experiment having taken place. Solar radiation would not have been detected, firstly because even this huge detector would not have been sufficiently sensitive, and secondly because radiation of wavelengths long enough to be picked up by this equipment would not have penetrated the ionosphere.

Two of Hertz's associates, Wilsing and Scheiner, tried to look for radio waves from the sun around 1896, and it may well be that Hertz himself was involved. In England, Sir Oliver Lodge made a serious effort to look for solar radio waves between 1894 and 1900. He placed a very crude detector "behind a blackboard or some other opaque substance," thus shielding out any visible light. Interestingly enough, the electrical interference in the city of Liverpool, where these experiments were made, was already strong enough to make Lodge give up his early attempts. Shortly afterwards, in 1901, a Frenchman, C. Nordmann, made another attempt to detect solar radio waves but was equally unsuccessful. Nordmann applied reasoning that was well ahead of his time. He went to the top of a high glacier, to be away from man-made radio noise and as high above the atmosphere as he could get. He suggested that the radio emission from the sun might vary with the solar cycle, and as a consequence that the radio emission from the sun might well originate in sunspots. Unfortunately, he only conducted his experiment for one day (the glacier was perhaps too cold under his feet) and then gave up. If he had been more patient, and had waited for a solar maximum (1901 was a solar minimum), he might have succeeded.

The reason for the long delay in further experimentation after these initial attempts may well be due to Planck, who announced his radiation theory in 1902. If this theory were correct, it followed that the radiation from the sun should be blackbody radiation, and the radio emission from a 6000°K blackbody was, of course, undetectable at that time. Similarly, radiation from the stars should be undetectable and one could in fact calculate that the planets and the Milky Way could not possibly give any detectable signals either. This is the unfortunate type of preconceived notion that throughout the history of science has delayed progress considerably, but fortunately is more than offset by chance discoveries or the occasional appearance of a brilliant theoretician or observer. As far as I know, no one consciously tried to look for radio waves from space until after Jansky's accidental discovery in 1932.

Everybody, of course, is familiar with the famous discovery of radio waves by K. G. Jansky, who in 1930 installed a novel rotatable directional antenna system to study the characteristics of radio noise as a function of time and direction. Jansky, of course, discovered thunderstorms both locally and at large distances, but he also noted a steady radiation that quite clearly was not caused by his receiver and that varied with direction and time. It is a great tribute to Jansky's scientific mind that, knowing nothing about astronomy when he started, he first eliminated the sun as the origin of the radiation; then, after having collected several months' worth of data, he deduced that the time difference in the reception of maximum intensity of this radiation (four minutes per day) must mean it had its origin outside the solar system. A year's observation enabled him to establish the position of the maximum of the radiation with an accuracy which, despite his long wavelength (14.6 meters) and his very wide beam width, was probably within a few degrees of being right. His paper, delivered before the Washington meeting of the International Scientific Radio Union (URSI) in 1933, marked the true beginning of radio astronomy.

The discovery was well publicized by Jansky's employer, the Bell Telephone Company, and radio listeners throughout the United States were allowed to listen in to the "hiss of the Universe." Jansky continued his observations off and on for another year or so, and published his final paper[1] in 1935. He concluded that the distribution of the sources of the radiation along the Radio Milky Way was disklike, similar to the distribution of stars in our Galaxy. He ruled out the stars as a source of radiation, as he could not detect any radiation from the nearest star, our sun. He also found that the characteristics of the noise were similar to those from the electric charges in a resistor, and suggested that the source of the radiation was in fact very hot charged particles in the interstellar medium. How right he was!

Jansky's was the first truly observational paper in radio astronomy. It was presented at the Detroit meeting of the Institute of Radio Engineers (IRE), and there were only 20 people in the audience!

Jansky's ability as a true scientist stands out even more strongly if we compare his achievements and deductions with those of several people in the United States and Japan who had noted a high degree of noise in their receivers before and after radio fadeouts. In 1938 an American paper suggested that this might be caused by charged particles from the sun hitting the ionosphere; in 1939 a Japanese paper concluded that the noise happened only during the daytime and came from high elevations. No one apparently thought of electromagnetic radiation from the sun itself.

Jansky's final proposal was that for better resolution and steerability, a 100-foot paraboloid should be constructed; preferably by one of the universities, where basic research has its place. It is sad to realize now that had the astronomical community listened, we might have advanced in our science much more rapidly than we did. We lost a great opportunity here, and we lost another because between 1932 and 1946, when radio astronomy really started, the low-frequency end of the radio window became almost entirely fogged over by the rapidly growing radio communications industry. A warning is in place here. Astronomers have to do battle for every Hertz of radio frequency; even the very shortest wavelengths penetrating through our atmosphere are threatened by our "civilization." Galileo was the first to put the optical telescope to scientific use, yet it was not really used extensively until the nineteenth century; the sunspot cycle was not discovered until 1840. Astronomy moved slowly in those days. It still moved slowly in the 1930s. Is it really moving faster in the 1970s?

Anyway, Mother Bell decided that now that we knew the radiation was there, let someone else discuss it further: Jansky must go back to the business at hand. Luckily, someone else did want to discuss it further. Kraus and Adel[2] briefly looked for radiation from the sun in 1934, but it was not until Grote Reber appeared on the scene that the subject was picked up again properly. Reber's account[3] of these early years is a gem to read. Reber reasoned that Planck's law predicts that "for radio waves at any probable temperature, the intensity per unit bandwidth is proportional to the square of the frequency"; he also knew of course that the higher the frequency, the better the resolution. Therefore, a very high frequency (or short wavelength) was indicated. With the occasional help of the village blacksmith, he constructed his backyard 30-foot diameter paraboloid in his hometown, Wheaton, Illinois, in 1937; the instrument had a surface accuracy of a few centimeters, and he had the foresight to leave a central hole for a possible future Cassegrainian or Gregorian arrangement, a scheme not used in radio astronomy until some 25 years later.

Reber started his observations at a 9-cm wavelength, without success. He promptly concluded that Planck's blackbody law was not valid for celestial radiation! So he went up to 33 cm (still a wavelength forty times smaller than Jansky's) and a sensitivity a hundred times greater. Again no success. This time he concluded that "perhaps the actual relation between intensity and frequency was opposite from Planck's Law," a conclusion which was later shown to be correct. "Being a stubborn Dutchman," says Reber, "this whetted my appetite even more," so up he went to 187 cm. Why did he choose that particular wavelength? Well, a circular wave-guide type antenna could be constructed for that wavelength out of a standard-size piece of aluminum! In spring, 1939, the equipment was installed, but the Milky Way transited during the day when the automobile interference was bad and the heat of the sun put the receiver out of balance. Reber was thus restricted to very cloudy mornings falling on weekends, when he was not at work (remember that this was a spare-time occupation) and there were few cars. He was finally successful. He located the Milky Way, and kept improving his equipment, tabulating meter readings every minute, and mapping point by point.

The first results were put before the astronomical community in the Astrophysical Journal in 1940.[4] When Otto Struve, the editor at that time, received the paper, he could find no referee for it. It was the first paper on radio astronomy submitted to an astronomical publication. The story goes that Struve finally traveled to Wheaton, inspected the telescope, talked to Reber, and accepted the paper!

A second paper, presenting a complete map, appeared in 1944.[5] In that paper Reber mentioned in passing the sun also emitted radio waves, and that if these were really of thermal origin, this would mean that the sun had a temperature of about a million degrees, "which had no meaning at the time."

In the meantime, Hey in England, working with meter-wave radar, and Southworth in the United States working at 3 to 10 cm, discovered that the sun was a powerful and highly variable radio source (but this information was of a military nature and thus was not generally available). On one day in 1942 all British radars were jammed by the enemy, so badly that some people feared a major attack. The enemy turned out to be the sun, and for many a student of very faint galactic and extragalactic sources, the sun remains an enemy, just as it is for the stellar observer, albeit for different reasons. Reber detected solar bursts in 1946, when he switched to 62-cm wavelength. The sun was strong, but on some days he also noted more automobile interference during solar transit than before or after! "Why the cars should pick this time to be particularly objectionable seemed quite mysterious," until he moved the antenna away from and back to the sun, and found that all radio waves came from the sun itself. The radio bursts from the sun, often tens to thousands of times more intense than its thermal emission, have at first sight very much the same characteristics as automobile ignition interference.

This then takes care of the early history of radio astronomy. What happened after the war? The radar and radio engineers found themselves with laboratories full of equipment and no prospective new enemy in sight. So at last they could devote their time to real basic research. And some of them turned to radio astronomy. I shall list only a few of the many discoveries that followed in rapid succession between 1945 and 1951. One man needs special mention. He is J. S. Hey, the wartime radar researcher. He was responsible for three major discoveries, maybe one third of all the major discoveries made in the subject so far. He discovered and described the radiation from the sun; he discovered that meteor trails produce radar echoes and detected new streams of meteors, thus starting a new era in meteor research; and he was the first to find a small source of radio emission, a radio "star," the famous extragalactic source Cygnus A.

This latter discovery warrants our attention for a moment, as it shows again the deductions an eminent scientist can make. During a survey of the sky at a 5-m wavelength, Hey, Parsons and Phillips[6] found short-period fluctuations (of the order of minutes or seconds) in the constellation Cygnus. The fluctuating source was smaller than two degrees, and Hey deduced that the fluctuations must come from a very small source, such as a star, rather than from the general interstellar medium which was thought to be responsible for the Milky Way emission. (Later it was found that the fluctuations were due to scintillations, the effect of the earth's ionosphere, just as small angular-size stars scintillate more violently than large planets.) Thus the first radio source was discovered.

In Australia, meanwhile, the Commonwealth Scientific and Industrial Research Organization (CSIRO) radio physics laboratory switched to peacetime research. A 1944 preliminary attempt by Kerr to observe the Milky Way was frustrated by wartime research, but in 1945 J. L. Pawsey and his colleagues started to study the sun, and for this they invented a novel instrument, the cliff interferometer. An old wartime radar antenna, mounted on a cliff overlooking the sea, was used as a Lloyds mirror interferometer, receiving both the direct rays from a rising or setting object and those reflected by the sea and thus traveling along a longer path. The interferometer provided high angular resolution and Pawsey was able in 1946 to locate some very strong disturbances over a huge sunspot that fortunately appeared a few days after the equipment had been assembled. The Australian work on the sun led to the development of P. Wild's most sophisticated solar radio spectrometers and interferometers. Throughout the Australian development

Pawsey was the leading spirit, and the leading position of Australia in radio astronomy is largely due to his enthusiasm and inspiring leadership, which continued until his early death in 1962.

In England, Martin Ryle and his group developed the two-element interferometer, and likewise studied the sun in 1946. Ryle's work, of course, led to the extensive development of the field of radio interferometry, which, with all its refinements is ultimately the only way that very high resolutions can be reached. Ryle could undoubtedly be called the father of both radio interferometry and radio cosmology. He and his group in Cambridge have set the pace for the investigation of extragalactic radio sources, which early in the 1950s led to the realization that the enormous intrinsic brightness of some types of sources could widen our observational horizon by an order of magnitude and eventually could help solve some of the burning questions of cosmology.

Although investigations of many different types were started in many countries, it is undoubtedly true that Ryle in England and Pawsey in Australia were by far the outstanding leaders in the field until the early 1950s.

Going back to the Australians for a moment, John C. Bolton and Gordon Stanley, after having seen Hey's discovery of a radio "star," put the cliff interferometer to work, found Cygnus A to be less than seven minutes of arc in diameter, and went on to discover several more of such discrete sources. They were the first to identify (in 1947) such a source with a visible object; this was the Crab nebula, the remnant of the supernova that exploded in the year 1054. This was a daring identification, as their positional accuracy was relatively good in one direction but not in the other. In order to get a different look at these sources they took their cliff interferometer to New Zealand, where instead of looking east across the ocean, they could look west. The accurate time of their rising *and* their setting allows a much better determination of the sources' coordinates.

The galactic radiation was mapped at a number of different wavelengths, confirming Jansky's and Reber's results. It was typical of that time that even though the lack of resolution of those early telescopes was well known, Oort and I in 1951 compared Bolton and Westfold's radio map with the distribution of mass in a model of the Galaxy, and found the two to be rather similar: the sources of radio emission seemed to be distributed much like the ordinary stars. A few years later it became clear that this was just a coincidence; with better resolution, the radio emission was found to be concentrated much closer to the galactic plane. The mechanism of this emission became clear around 1950 through the work of Alfvén and Herlofson and Kiepenheuer, later developed in detail by Ginzburg and Shklovski. Although the radiation at high frequencies is clearly due to thermal emission from hot gas, the low-frequency radiation is due to the synchrotron process, first detailed by Schwinger in the early 1900s. Verification of this theory was obtained in the late fifties, by the detection of the predicted linear polarization of the galactic radiation.

My final point will center around the prediction of the 21-cm line. In a symposium held in Leiden, The Netherlands, in 1944, the field of radio astronomy was discussed. Van de Hulst[7] concluded that astronomers did not pay much attention to the existing data on radio astronomy, because they were too rough; no good discussion was possible. This seems to have been the general attitude of astronomers in those days: "We'll be glad to discuss and use your data, but you radio engineers had better come up with something good first." Van de Hulst also concluded that in any case the production of radio waves in the interstellar gas was such a small portion of the energy budget that purely theoretical considerations of their production would not teach anything new! After having damned radio astronomy in this way, however, Van de Hulst produced what in essence was the first scholarly paper in the field, containing three (not one) predictions which all came true. The paper is an outstanding example of deep insight into the field of astrophysics, of how to apply that insight to a new and unexplained phenomenon, and of how to direct further observations. Expanding on Henyey and Keenan's 1940 article[8] on the spectrum of the free-free emision from the interstellar gas (Reber[4] was actually the first to point out that free-free emission is the source of the radiation) he noted the uncertainties in the theory, as most of the hot gas is in H II regions and is not smoothly distributed. He also discussed the possibility of observing the H II regions individually, and calculated the strength of the recombination lines (presently a source of all sorts of new information about H II regions). He concluded that the theoretical spectrum more or less fitted Reber's data, but that Jansky's low-frequency data were ten times too high. "It seems possible," he said, "that this is due to his poorly known directivity." The astronomer was again reluctant to accept new data that did not fit his theory.

At the suggestion of Oort, Van de Hulst made a very interesting calculation about how at radio wavelengths we can distinguish between an expanding and a static universe, because the spectrum of the radio emission is entirely different from that of the optical and ultraviolet spectra of galaxies. He could completely eliminate, on the basis of the observations then available, the theory of the static universe, where red shift is not due to the Doppler effect. Van de Hulst thus started here the field of radio cosmology!

Finally, in half a page, he showed that the spin transition should be observable in the neutral hydrogen atom at 21 cm. His discussion followed Oort's suggestion that if spectral lines could be found in the radio region, the kinematics and dynamics of the entire Galaxy could be studied. Van de Hulst's paper, therefore, was a milestone in three different subjects: the 21-cm line, radio cosmology, and the hot interstellar gas. He has never been given credit for the latter two.

As we know, it was not until 1951 that Ewen and Purcell, followed within two months by the Dutch group and the Australians, detected the line. Reber might have detected it in 1947, when he assembled a receiver for it, but because of personal reasons he "terminated his operations in Illinois" before he tried it out.

Should we go on here? I don't think so; we come to textbook material.

Some memories might be in place, such as those of the early days in Kootwyk, The Netherland. The classical map of the spiral structure of the Galaxy depends on the data obtained between 1953 and 1955, using a 25- foot dish, moved in elevation and azimuth (to follow a point in the sky) by turning two small hand cranks every 2.5 minutes for two years (student labor!), and on data obtained from the Australian 40- foot dish, which could not be cranked at all as it was a transit instrument. I still remember the reduction of the first real data, leading to the classical 1952 paper by Van de Hulst, Oort, and Muller, outlining the rough spiral structure. All Leiden astronomy students were herded into the lecture room and were given sheets of recorder paper, and within a week we had everything reduced to intensities as a function of velocity and position.

Fred Whipple recalls the first grant given to radio astronomy by an astronomical institution: $50, given to him by H. Shapley in 1937 to buy a radio receiver. Whipple and Greenstein[9] had just finished a paper showing that radiation from interstellar dust could not possibly explain Jansky's observations. Whipple was going to build a diamond-shaped (rhombic) antenna on the top of the 61-inch dome at the Agassiz Station. The dome would provide an excellent base for a rotatable telescope!

Finally, an interesting question: why were astronomers slow to accept radio as another tool? Was it fear of electronics? Maybe, but I think Van de Hulst summed it up much better: we had the feeling that, with perhaps a few exceptions, nothing new could be learned. And then too, there was so much to do in the old established field. The mountain observatories were buzzing. Baade wrote to Bok in 1953, when Bok started radio astronomy at Harvard: "Why bother, the Dutch have done it all." Radio astronomy seemed so far removed that it was not really considered astronomy, but rather engineering; the results should be treated as entirely separate from those of "real astronomy". How many schools still teach a course called "radio-astronomy" in which the sun, galactic structure, and cosmology are all discussed? I suspect there are many. But are there courses called "photography" where these subjects are discussed? I doubt it. At the University of Maryland, the teaching of radio astronomy fits into the observational astronomy cycle, but quasars fall under extragalactic astronomy, and the sun belongs under solar physics.

One man stands out as a classical astronomer who very early in the game saw the importance of radio astronomy as a tool and used it as a tool and pushed for it as a tool, from the time when he first knew of the existence of radio waves from space. Jan H. Oort organized the Dutch Symposium of 1944; he acquired old German radar dishes in 1946 before they were demolished; he started planning for a large telescope in 1950. In 1956 the Dutch 82-foot telescope was the largest radio telescope in the world (followed shortly by the Jodrell Bank instrument). Planning for the largest radio telescope now in operation, the Westerbork Array, started in 1959. I recall a note Oort wrote on top of a preprint of Ryle's first cosmology paper, around 1951: "This is the most fascinating and far-reaching paper I have ever seen." Oort realized that radio astronomy was a new tool. I think that realization was lacking in almost all the astronomical world, and it is only in the last ten years, when striking new discoveries have been made, not "just things we know already, like galaxies and H II regions," that the full impact of radio techniques on astronomy has been realized. We have finally woken up, but it took 10^{60}-erg alarm clocks!

Acknowledgments

A list of references to early papers would cover many pages. I have relied heavily on the excellent 1958 Radio Astronomy Issue of the Proceedings of the IRE. The introductory article by Haddock in that issue contains a wealth of references.[10] I have also relied heavily on the introductory chapters of many textbooks and popular books on radio astronomy, notably those by Kraus,[2] Smith[11] (to whom I owe the story on Edison), and Smith and Carr[12] (where I found the story on Nordmann). Because of the abundance of references in other review papers, notably Haddock's,[10] I have given very few references in this paper.

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Discussion

DR. W. LILLER: Thank you. I just wanted to say that the Harvard 61-inch optical reflector was used in 1954 to observe the supernova that Dr. Westerhout mentioned.

DR. K. FRANKLIN (*American Museum-Hayden Planetarium, New York, N.Y.*): I have a footnote about the Bell Telephone Company. A lady teacher on Long Island, who has come to some of our conferences at the planetarium, tells us that her grandfather was the fellow in charge who removed Jansky from this work and put him onto other things. She says he used to remark that if he had ever made a mistake in his life, that was it.

DR. WESTERHOUT: Thank you, Dr. Franklin. Dr. Franklin, of course, is the man who (with Burke) discovered Jupiter's radio bursts in 1955. At first they attributed them to a local farmhand milking cows every morning at 7 o'clock. But this farmhand somehow seemed to change the time at which he got up by four minutes every day. The story goes that Dr. Burke remarked one early morning: "What is that bright star up there?" It was the planet Jupiter, and this remark led Dr. Franklin to plot the radio signals as a function of Jupiter's position, finding a beautiful correlation.